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**Exploration Systems Mission Directorate**

**National Aeronautics and Space Administration, Headquarters  
Washington DC 20546-0001**

## **Exploration System of Systems Technical Requirements Document**

**Preliminary Version – Revision E  
30 Mar 2005**

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# 1 Scope

## 1.1 Identification

This document is a summary of the NASA Exploration System of Systems Technical Requirements. When combined with the Exploration System of System Programmatic Requirement and Guidelines (ESMD-RQ-0021), they represent a first-level functional decomposition of the requirements expressed in *A Renewed Spirit of Discovery: The President's Vision for U.S. Space Exploration, January, 2004*. The Vision is expressed in requirements form in the *Level 0 Exploration Requirements for the National Aeronautics and Space Administration, SA-0001, May 4, 2004*.

The capabilities expressed in this document will evolve and expand over time, employing the Spiral Development Process to develop human-crewed, cargo, and robotic flight and ground systems to accomplish The Vision. Emphasis has been on the Crew Exploration Development and Test requirements (Exploration Spiral 1) and the Lunar Exploration requirements (Exploration Spirals 2&3), that provide long-duration human lunar exploration capability. Requirements development for Exploration beyond Spiral 3 (e.g., human-Mars exploration) will be undertaken in the future. The controlling authority for this document is the Exploration Systems Mission Directorate (ESMD), Requirements Formulation Division, NASA Headquarters.

## 1.2 Document Overview

This document provides the Exploration System of Systems technical requirements that are then functionally decomposed and captured in individual Exploration Systems. The Exploration Systems hierarchy shown in Figure 1 explains the hierarchy of requirements documents that flow down from The Vision. The relationship of this document to other Exploration Systems requirements documents is shown in Figure 2.

Note: Where a requirement is expressed with "threshold and objective" values, it has been determined that performance above the threshold (minimum performance level) is of value to NASA as a desired "objective". Where no objective value is expressed, the value shown is the threshold requirement. Section 1 of this document contains background information with no direct requirements. Section 2 contains the applicable documents that Explorations Systems must comply with, as specified. Section 2 also contains reference documents that are for information only, that do not contain compliance requirements. Section 3 contains Exploration System of Systems requirements, beginning in Section 3.1. Section 4 contains a glossary of exploration terms, an acronym list, and a requirements taxonomy table.

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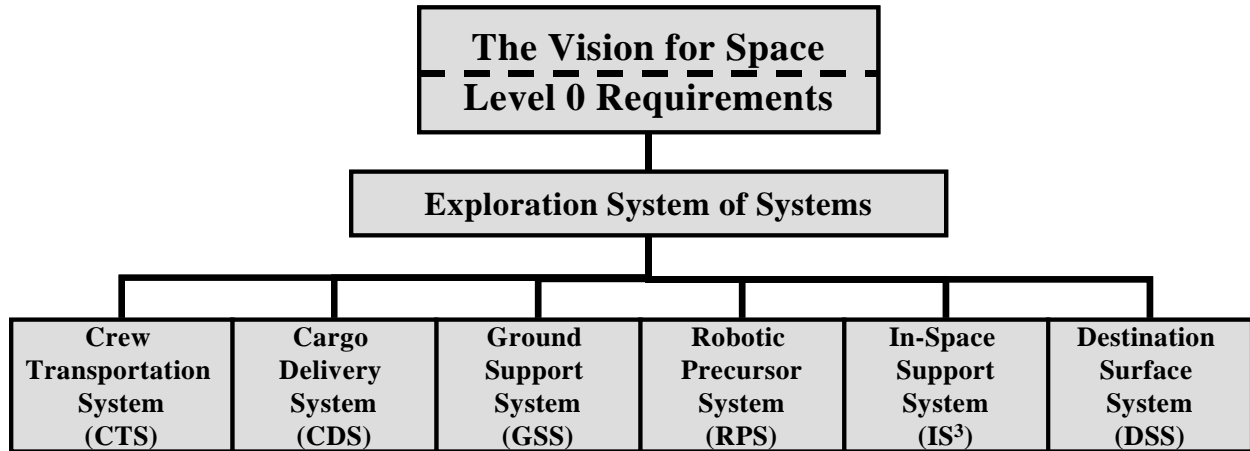


Figure 1: Exploration System of Systems Hierarchy

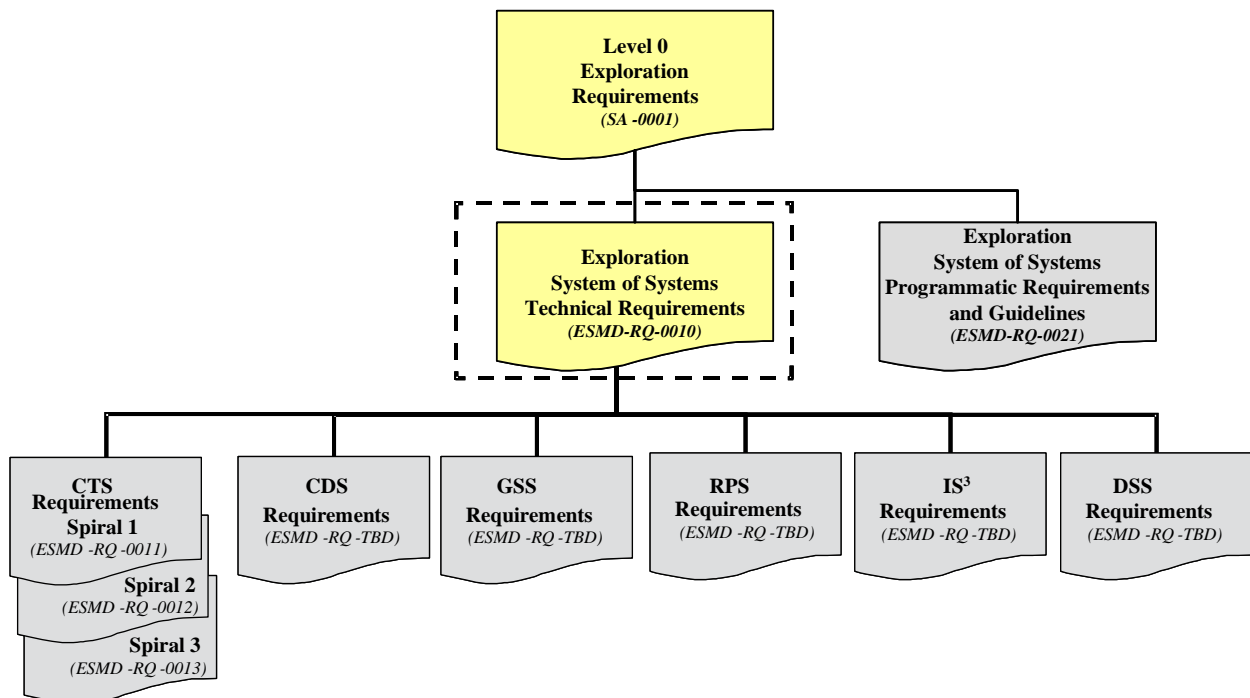


Figure 2: Exploration System Requirements Document Tree



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## 2 Documents

### 2.1 Applicable Documents

The following documents form a part of this requirements document to the extent specified herein. The version of the document applicable will be the latest revision at the time of contract award unless otherwise specified.

#### 2.1.1 Government Documents

The Vision for Space Exploration (NP-2004-01-334-HQ)  
Level 0 Exploration Requirements for the National Aeronautics and Space Administration (SA-0001)  
NPR 7150, Software System Engineering Requirements  
NPR 8705.2, Human Rating Requirements and Guidelines for Space Flight Systems  
NPD 8710.3, NASA Policy for Limiting Orbital Debris Generation  
NPR 8715.3, NASA Safety Manual  
NPR 8715.x, NASA Range Safety Program (**in draft**)  
NPR 8020.12, Planetary Protection Provisions for Robotic Extraterrestrial Missions  
NASA-STD-8719.13, Software Safety NASA Technical Standards  
NEDD ESS Natural Environments Definition for Design (**TBD-101**)

#### 2.1.2 Non-Government Documents

Reserved.

### 2.2 Reference Documents

The following documents specified herein are for reference only. Current document versions are referenced.

#### 2.2.1 Government Documents

ESMD-RQ-0005, Lunar Architecture Focused Trade Study Final Report  
ESMD-RQ-0006, Lunar Architecture Broad Trade Study Final Report  
ESMD-RQ-0016, STTP-2 Meeting Minutes  
ESMD-RQ-0018, Draft Polar Lunar Landing Site Rationale  
ISBN 0-309-07031, Astronomy and Astrophysics in the New Millennium, National Academies of Science  
NASA-STD-3000, Vol. I-IV, Man-Systems Integration Standards  
NPR 1000.2, NASA Strategic Management Handbook  
NPD 1050.1G, Authority to Enter into Space Act Agreements  
NPD 1080.1A, NASA Science Policy  
NPD 1200.1B, Internal Management Controls and Audit Liaison  
NPD 1280.1, NASA Management System Policy

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NPD 1360.2A, Initiation and Development of International Cooperation in Space and Aeronautics Programs, NPD 1360.2A  
 NPR 1385.1, Public Appearances of NASA Astronauts and Other Personnel  
 NPD 1387.1E, NASA Exhibits Program  
 NPR 1387.1, NASA Exhibits Program  
 NPD 1387.2F, Use, Control, and Loan of Lunar Samples for Public and Educational Purposes  
 NPD 1600.2C, NASA Security Policy  
 NPR 1620.1A, Security Procedural Requirements  
 NPR 1800.1, NASA Occupational Health Program Procedures  
 NPR 1800.2B, NASA Occupational Health Program  
 NPD 1810.2, NASA Occupational Medicine Program  
 NPD 1820.1B, NASA Environmental Health Program  
 NPD 2200.1, Management of NASA Scientific and Technical Information (STI)  
 NPR 2200.2A, Requirements for Documentation, Approval, and Distribution of NASA Scientific and Technical Information (STI)  
 NPD 2800.1, Managing Information Technology  
 NPR 2800.1, Managing Information Technology  
 NPD 2810.1C, NASA Information Security Policy  
 NPR 2810.1, Security of Information Technology  
 NPD 2820.1A, NASA Software Policies  
 NPD 3310.1A, Distinguishing between Contractor and Civil Service Functions  
 NPD 5101.32B, Procurement  
 NPR 5600.2B, Statement of Work (SOW); Guidance for Writing Work Statements  
 NPR 6000.1F, Requirements for Packaging, Handling, and Transportation for Aeronautical and Space Systems, Equipment, and Associated Components  
 NPD 7100.10D, Curation of Extraterrestrial Materials  
 NPD 7120.4B, Program/Project Management  
 NPR 7120.5B, NASA Program and Project Management Processes and Requirements Approval Authorities for Facility Projects. NPD 7330.1F, Approval Authority for Facility Projects  
 NPD 7500.1A, Program and Project Logistics Policy  
 NPR 7500.1, NASA Technology Commercialization Process  
 NPR 8000.4, Risk Management Procedural Requirements  
 NPD 8020.7F Biological Contamination Control for Outbound and Inbound Planetary Spacecraft  
 NPR 3020.12B, Planetary Protection Provisions for Robotic Extraterrestrial Missions  
 NPD 8610.7A, Launch Services Risk Mitigation Policy for NASA -Owned Or NASA -Sponsored Payloads  
 NPD 8610.23A, Technical Oversight of Expendable Launch Vehicle (ELV) Launch Services  
 NPD 8610.24A, Expendable Launch Vehicle (ELV) Launch Services Pre-launch Readiness Reviews  
 NPD 8700.1B, NASA Policy for Safety and Mission Success  
 NPD 8700.2A, NASA Policy for Safety and Mission Assurance (SMA) for Experimental Aerospace Vehicles (EAV)  
 NPD 8700.3A, Safety and Mission Assurance (SMA) Policy for NASA Spacecraft, Instruments, and Launch Services  
 NPR 8705.3, Safety and Mission Assurance (SMA) Requirements for Experimental Aerospace Vehicles (EAV)  
 NPR 8705.4, Risk Classification for NASA Payloads  
 NPR 8705.5, Probabilistic Risk Assessment (PRA) Procedures for NASA Programs and Projects

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NPR 8715.1, NASA Safety and Health Handbook Occupational Safety and Health Programs  
 NPD 8720.1B, NASA Reliability and Maintainability (R&M) Program Policy  
 NPD 8730.2B, NASA Parts Policy  
 NPD 8730.4A, Software Independent Verification and Validation (IV&V) Policy  
 NPR 8735.2, Management of Government Safety and Mission Assurance Surveillance Functions for NASA Contracts  
 NPD 8820.2A, Design and Construction of Facilities  
 NPR 8820.2E, Facility Project Implementation Guide  
 NPD 8820.3, Facility Sustainable Design  
 NPD 8900.1F, Medical Operations Responsibilities in Support of Human Space Flight Programs  
 NPD 9501.1G, NASA Contractor Financial Management Reporting System  
 NPR 9501.2D, NASA Contractor Financial Management Reporting  
 NPD 9501.3A, Earned Value Management  
 NPR 9501.3, Earned Value Management Implementation on NASA Contracts

## 2.2.2 Non-Government Documents

Reserved.

## 3 System Requirements

The following text does not provide, nor represent specific requirements, but is provided as context for the requirements that follow, beginning in section 3.1.

### System Description

The Vision for Space Exploration requires NASA to implement an effective and exciting program of exploration and discovery. Sustained and affordable human and robotic missions will extend the human presence across the solar system. Innovative technologies, knowledge, and infrastructures will need to be developed. Over the next two decades, NASA plans to develop a number of new capabilities and systems that are critical to enabling safe and successful human and robotic missions. Vehicle elements to be fielded within this System of Systems will use a “spiral development” approach. In spiral development, the detailed end-state requirements are not known at program initiation. Requirements are refined through system development and demonstration, risk management and continuous user feedback. This approach will build on the experience gained in early Exploration Spirals, to provide flexibility in responding to scientific discoveries and to incorporate new technologies. Robotic Precursor Missions to the Moon and Mars will provide information necessary to conduct future human exploration (i.e., topography mapping, gravity maps, resource identification). In addition, Robotic Precursor Missions will serve as opportunities for advanced technology demonstrations.

### Exploration Spiral 1/Crew Exploration Development and Test

Exploration Spiral 1 will establish the capability to test and checkout Crew Transportation System (CTS) elements in Low Earth Orbit (LEO) in preparation for future human exploration missions to the Moon. The capabilities necessary to satisfy the Spiral 1 objectives consist of a Crew Exploration Vehicle (CEV), a Crew Launch Vehicle (CLV), and ground support infrastructure. The CEV and CLV will safely transport the crew from the surface of the Earth to LEO, and return them to the Earth’s surface at the

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completion of the mission. Demonstration of CEV and launch system performance are critical to enabling Spiral 1 objectives of safe transportation of the crew. Successive demonstrations of the CEV and launch system (including the ability to perform ascent and entry aborts) will begin with a series of risk reduction flight tests, and lead up to crewed CEV operational capability to support human exploration missions beyond LEO. The CEV must have a high degree of automated control to accomplish the early un-crewed test flights. As exploration capabilities necessary for future spirals are developed, they will be tested with the CEV in the space environment to prepare for future exploration missions. Robotic exploration missions during Spiral 1 will investigate the lunar environment and provide the needed information to prepare for safe landings and human exploration of the lunar surface. Robotic missions will also develop and mature autonomous technologies for use in the CEV.

#### Spiral 1 Flight Hardware Functional Descriptions:

##### Crew Launch Vehicle:

Will provide the propulsive force necessary to launch the CEV into LEO.

##### Crew Exploration Vehicle:

Will provide the necessary crew habitation functions during the ascent, on-orbit, and entry phases of the mission, including aborts. Will also provide all maneuvering capability during orbit operations and entry (including entry phase of an abort).

##### Robotic Precursor System:

Will provide measurements, technology demonstrations, and may provide infrastructure in advance of human missions.

##### Ground Support System:

Ground based facilities and capabilities will provide the ability to plan, train, process, launch, operate flight systems, as well as land, recover, refurbish or dispose of those systems.

### **Exploration Spiral 2/Global Lunar Access for Human Exploration**

Exploration Spiral 2 will establish the capability to conduct human exploration missions to any location on the surface of the Moon without pre-positioned surface infrastructure. This Spiral 2 capability will likely be utilized to conduct human exploration of potential lunar base sites prior to the delivery of habitats and surface power systems (Destination Surface Systems). This capability could also be utilized to place humans at the lunar base camp location for habitat and surface power systems final assembly tasks. Once the lunar base is established, this Spiral 2 capability could be utilized to explore locations which are not accessible via surface mobility assets. The systems necessary to satisfy Spiral 2 objectives consist of those developed in Exploration Spiral 1, or derivatives of those systems, plus Earth Departure Stage(s) (EDS) necessary to transport elements to the lunar vicinity as well as the Lunar Surface Access Module (LSAM) that will provide the capability for the crew to access the lunar surface. The Cargo Delivery System will deliver un-crewed elements of the Crew Transportation System into LEO and/or lunar orbit (e.g., EDS). Spiral 2 will include successive flight tests to demonstrate the flight characteristics of the CEV, EDS, and LSAM to gain knowledge of how the systems perform at greater distances from Earth and increasing levels of autonomy. Focused robotic precursor technology demonstration missions to Mars are also anticipated within this Spiral.

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### Spiral 2 Flight Hardware Functional Descriptions:

#### Crew Launch Vehicle:

Will provide the necessary propulsive force to launch the CEV and other mission elements into LEO.

#### Crew Exploration Vehicle:

Will provide the necessary crew habitation functions from launch to lunar orbit and return to the Earth surface, including aborts during Earth ascent. The CEV will also provide the necessary propulsive accelerations to return the mission crew from lunar orbit, independent of orbital alignment, for direct entry at Earth. The CEV will rendezvous and dock with other mission elements, such as the EDS and LSAM, in both LEO and lunar orbit. In addition, the CEV will operate un-crewed in lunar orbit while the crew is on the surface of the Moon.

#### Earth Departure Stage(s):

Will provide the necessary propulsive accelerations needed to transfer the various flight elements (CEV and LSAM) from LEO to lunar orbit, and provide the deceleration for lunar orbit insertion.

#### Lunar Surface Access Module:

Will provide the necessary crew habitation and transportation functions from lunar orbit to the lunar surface and during return to lunar orbit; will provide crew habitation during lunar surface operations. In addition, the LSAM will provide the capability for the crew to conduct science and perform routine Extra-Vehicular Activity (EVA) on the surface of the Moon.

#### Cargo Delivery System:

Will deliver un-crewed elements of the CTS into LEO and/or lunar orbit. CDS elements include the Cargo Launch Vehicle and the EDS.

#### Robotic Precursor System:

Will provide measurements, technology demonstrations, and may provide infrastructure in advance of human missions.

#### Ground Support System:

Ground based facilities and capabilities will provide the ability to plan, test, train, process, launch, operate flight systems, as well as land, recover, refurbish or dispose of those systems.

### **Exploration Spiral 3/Lunar Base and Mars Testbed**

Exploration Spiral 3 will establish the capability to conduct routine human long-duration missions at a lunar base to test out technologies and operational techniques for expanding the human presence to Mars and beyond. Missions in Spiral 3 will extend up to several months in duration at the lunar poles or equatorial region in order to serve as an operational analog of future Mars missions. Spiral 3 will require the development and deployment of habitats and surface power systems. These Destination Surface Systems (DSS) will be delivered to a selected location in the polar or equatorial region by the Cargo Delivery System (CDS). The number, type, and sequencing of these CDS missions have not yet been specifically defined. Once the surface systems are in place, successively longer missions will be

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conducted to increase the understanding of system technical performance (including health and human systems), and to provide increasing levels of operational autonomy capabilities that will be necessary for future human Mars exploration missions. The Spiral 2 capability for global access is retained in Spiral 3, and will allow exploration missions to locations not accessible from the base camp via surface mobility assets.

Spiral 3 Flight Hardware Functional Descriptions:

Crew Launch Vehicle:

Will provide the necessary propulsive force to launch the CEV and other mission elements into LEO.

Crew Exploration Vehicle:

Will provide the necessary crew habitation and health maintenance functions from launch to lunar orbit and return to the Earth surface, including aborts during Earth ascent. The CEV also will provide the necessary propulsive accelerations to return the mission crew from lunar orbit, independent of orbital alignment, for direct entry at Earth. The CEV will rendezvous and dock with other mission elements, such as the EDS and LSAM, in both LEO and lunar orbit. In addition, the CEV will operate un-crewed in lunar orbit while the crew is on the surface of the Moon.

Earth Departure Stage(s):

Will provide the necessary propulsive accelerations needed to transfer the various flight elements (CEV, LSAM, and cargo vehicles) from LEO to lunar orbit and provide the deceleration for lunar orbit insertion.

Lunar Surface Access Module:

Will provide the necessary crew habitation and transportation functions from lunar orbit to the lunar surface, and return to lunar orbit. In addition, the LSAM will provide the capability for the crew to perform EVA on the surface of the Moon in order to transition to the surface elements for the long duration missions. The LSAM will remain on the surface of the Moon during the long-duration surface missions.

Cargo Delivery System:

Will deliver un-crewed elements of the Crew Transportation System into Low Earth Orbit and/or lunar orbit. CDS elements include the Cargo Launch Vehicle and the EDS. The CDS will also deliver elements of the DSS from a low lunar orbit to the desired location on the surface of the Moon. The CDS elements have not been completely identified at this time, but should include a Cargo Launch Vehicle, Cargo Destination Landing System, and the EDS.

Destination Surface System:

Will provide crew support capabilities to enable long-duration surface missions. The elements that comprise this system have not been completely defined at this point, but will provide functionality including habitation, communication, power, extended range mobility, enhanced science capabilities, etc. DSS will provide the capability for the crew to conduct long-duration surface science, and perform EVA on the surface of the Moon.

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#### Robotic Precursor System:

Will provide measurements, technology demonstrations, and may provide infrastructure in advance of human missions.

#### Ground Support System:

Ground based facilities and capabilities will provide the ability to plan, test, train, process, launch, operate flight systems, as well as land, recover, refurbish or dispose of those systems.

## 3.1 Mission Definition

**ESS0040** The Exploration System of Systems shall conduct human exploration of the Moon using established safety requirements and processes for development and operations.

*Rationale :* Flow-down of Level 0 Requirement (1), broken into specific elements for traceability.

**ESS0050** The Exploration System of Systems shall conduct human exploration of Mars using established safety requirements and processes for development and operations.

*Rationale :* Flow-down of Level 0 Requirement (1), broken into specific elements for traceability.

**ESS0060** The Exploration System of Systems shall conduct human exploration to other destinations, as identified in the Exploration Spirals, using established safety requirements and processes for development and operations.

*Rationale :* Flow-down of Level 0 Requirement (1), broken into specific elements for traceability.

**ESS0010** The Exploration System of Systems shall conduct robotic exploration of the Moon using established safety requirements and processes for development and operations.

*Rationale :* Flow-down of Level 0 Requirement (1), broken into specific elements for traceability.

**ESS0020** The Exploration System of Systems shall conduct robotic exploration of Mars using established safety requirements and processes for development and operations.

*Rationale :* Flow-down of Level 0 Requirement (1), broken into specific elements for traceability.

**ESS0030** The Exploration System of Systems shall conduct robotic exploration of other solar system destinations and destinations beyond the solar system, as identified in Exploration spirals, using established safety requirements and processes for development and operations.

*Rationale :* Flow-down of Level 0 Requirement (1), broken into specific elements for traceability.

**ESS0080** The Exploration System of Systems shall explore Jupiter's moons, asteroids, and other bodies to search for evidence of life, to understand the history of the solar system, and to search for resources.

*Rationale :* Direct flow-down from Level 1 Exploration Objective (1.3), contained in Level 0 Requirements document. Robotic exploration of Europa was ranked as the top priority of the Decadal Survey. These programs may spawn technology breakthroughs that facilitate human exploration of the

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Moon and Mars.

Reference: “New Frontiers in Solar System Exploration: An Integrated Strategy”, National Research Council, 2003.

**ESS0070** The Exploration System of Systems shall demonstrate power generation, communication, propulsion, life support, and other key capabilities required to support human and robotic exploration of Mars and other destinations.

*Rationale* : Direct flow-down from Level 1 Exploration Objective (1), contained in the Level 0 Requirements document. New technologies and capabilities such as closed loop life support, power generation (solar or non-solar) and propulsion advances are required for human exploration of Mars.

**ESS0680** The Exploration System of Systems shall provide the infrastructure necessary to support Exploration missions.

*Rationale* : This requirement is flowed down from the Level 0 Exploration Requirements (1.1): “NASA shall develop the innovative technologies, knowledge, capabilities, and infrastructures to support human and robotic exploration”. The System of Systems infrastructure will be vital to successful execution of Exploration missions.

Infrastructure will be needed to provide range accommodations, facilities (planning, training, and operations), platforms, communications systems, transportation systems, outpost accommodations, equipment, and other command, communication, control and computer resources.

**ESS0570** The Exploration System of Systems shall provide ground support services in support of Exploration missions.

*Rationale* : The capabilities necessary to satisfy this requirement include processing, integrate, test, launch, operation, and recovery or dispose of Exploration flight elements (as appropriate). It also includes search and rescue operations for recovery of the flight crew.

NASA must utilize an aggregate infrastructure capability to implement this requirement. This infrastructure must process flight hardware from completion of development through launch. This infrastructure must also provide for ground control functions (including human systems monitoring) during Exploration missions, and recover the CEV and crew at mission completion.

**ESS0690** The Exploration System of Systems shall meet the failure tolerance requirements during operations in space without the use of crew Extra-Vehicular Activity (EVA).

*Rationale* : Using EVA as a leg of failure tolerance puts the crew at additional risk. The system design should be robust and reliable enough that EVAs would only be needed to recover from failures that are impractical to adequately protect through redundancy or other means.

**ESS0700** The Exploration System of Systems shall execute nominal assembly operations in flight (e.g., docking or mating of two or more elements) without the use of crew EVA.

*Rationale* : This requirement will impact the design of the System of Systems when operations call for flight element assembly or integration in Low Earth Orbit or lunar orbit. As demonstrated in the assembly of the space station, allowing the program to use EVA for this assembly would result in higher



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training costs, additional risk to the crew, and extended mission durations in Low Earth Orbit prior to departure for the destination. When docking or mating of elements is required for return to Earth, allowing EVA for the nominal operation would increase risk to the crew, complicate the return scenario, and extend the amount of time required to return the crew to Earth, which is not acceptable for contingency returns.

**ESS0090** The Exploration System of Systems shall provide information, data, and scientific opportunities to support educational outreach activities and public awareness campaigns.

*Rationale :* The Level 0 Requirement (6) states that "NASA shall identify and implement opportunities within missions for the specific purposes of inspiring the Nation." This requirement is a flow-down to the Exploration System of Systems to provide for all the data (real time and non-real time) and information necessary to inform the general public and inspire a new generation of scientists, mathematicians, and engineers in our educational institutions. This requirement is written to serve as a parent requirement to technical communication capabilities necessary to provide video, voice and data to the general public via print, broadcast and electronic media.

**ESS0640** The Exploration System of Systems shall be designed to be operated in and after exposure to the natural environments as defined in the ESS Natural Environments Definition for Design (NEDD) document.

*Rationale :* The ESS NEDD will provide common definitions of the Solar System natural environments that will be encountered by exploration spacecraft. Compliance with this document will ensure systems are designed to operate in the appropriate natural environments.

## 3.2 Spiral Definition

### 3.2.1 Exploration Spiral 1 (S1)

**ESS0100** The Exploration System of Systems shall demonstrate human spaceflight capabilities in Low Earth Orbit (LEO) to prepare for future exploration missions.

*Rationale :* Successive demonstration of capabilities necessary to expand exploration to further destinations is a fundamental strategy for spiral development. Capabilities and infrastructure developed in early spirals are utilized to test and emplace systems needed for subsequent spirals. In addition, early spirals will serve as the building blocks for subsequent spirals, capitalizing on new technologies and operational concepts gained from previous missions. Successful demonstration of the Crew Transportation System in LEO with the Ground Support System is a necessary element in the progression to human exploration beyond LEO.

**ESS0110** The Exploration System of Systems shall conduct Robotic Precursor Missions to lunar orbit and the lunar surface to prepare for future human exploration.

*Rationale :* Further definition of Spiral 1. Robotic Precursor Missions will provide information necessary to conduct future human exploration (i.e., topography mapping, gravity maps, and resource identification). In addition, Robotic Precursor Missions will serve as opportunities for demonstration of advanced technologies.

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### 3.2.2 Exploration Spiral 2 (S2)

**ESS0120** The Exploration System of Systems shall demonstrate the capabilities necessary to prepare for long-duration human exploration of the Moon.

*Rationale :* This requirement is a flow-down of Level 0 Exploration Requirement (1.3) “NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations.” Spiral 2 is primarily a preparatory step toward long-duration exploration on the moon, which will, in turn, be used to prepare for Mars exploration.

**ESS0130** The Exploration System of Systems shall conduct human lunar exploration missions to further science.

*Rationale :* This requirement is a flow- down of Level 0 Exploration Requirement (1.3) “NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations.” This requirement captures the science objective of exploration.

**ESS0150** The Exploration System of Systems shall conduct human exploration missions with a surface duration (threshold) of 4 days (**TBR-2**), and an objective of 7 days (**TBR-5**) to any designated location on the lunar surface (global lunar access).

*Rationale :* This requirement establishes the fundamental capability to send humans to any location on the moon and return them to Earth. This capability will be used initially for extended duration exploration at potential sites of a lunar base camp and for any final assembly tasks prior to the base camp initial operating capability (IOC). Once long duration missions at the lunar base are started in Spiral 3, this Spiral 2 capability will be used for crew transport to/from the lunar base and for missions to locations on the lunar surface that are not accessible via surface mobility from the lunar base. Analysis indicates that 4-7 day surface duration is bounded by the lander capability and, for mid latitude mission, the return plane change requirements. Also, this requirement does not imply the ability to go anywhere on the Moon at any time. Thermal constraints on a system designed for polar missions may restrict when a given non-polar mission can be conducted. However, the capability for humans to explore any area of exploration interest on the lunar surface is provided in this Spiral.

References: ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results.”

TBD/TBR Closure: This capability is driven primarily by anytime return and will be established during the CE&R studies. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

**ESS0160** The Exploration System of Systems shall conduct human exploration on the lunar surface with a threshold of 4 crew members, and an objective of 6 crew members (**TBR-15**).

*Rationale :* A 4 person crew is the minimum number required to demonstrate operations concepts for exploring more distant destinations such as Mars. A 4 person crew (threshold) allows two EVA teams (2 crew per team) to operate simultaneously or in series while providing the capability for operational assistance from the non-EVA crew. A 6 person crew (objective) represents the most likely Mars exploration crew size, based on previous studies. However, since human rated launch capability is likely

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to be a limiting factor on CEV capability, 6 person crew size is carried as an objective only. Lower level requirements for each element will specify the capability to operate with fewer than 4 or 6 crew. Human exploration includes the use of robotic elements as part of the system.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results", ESMD-RQ-0016, "STTP-2 Meeting Minutes."

TBR-15 Closure: Further surface scenario assessments are required during the CE&R study phase. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

**ESS0170** The Exploration System of Systems shall provide a minimum flight rate capability of 1 human exploration mission to the lunar surface per year (**TBR-6**).

*Rationale* : This requirement is a flow-down of Level 0 Requirements (1) calling for "a safe, sustained, and affordable robotic and human program."

The Exploration System of Systems must be designed to support and be available for a minimum mission frequency in order to provide a sustainable Exploration program. Spiral and mission objectives must be achieved efficiently in order to achieve the challenging Level 0 milestones set for human exploration of the Moon, and ultimately Mars. A minimum flight rate should also be sufficient to support efforts to maintain flight and ground crew proficiency.

TBR-6 Closure: Additional data will be developed during the CE&R studies. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

**ESS0180** The Exploration System of Systems shall provide a maximum flight rate of (**TBD-3**) exploration missions to the lunar surface per year.

*Rationale* : Budgets are likely to determine the actual frequency of missions. However, the system must be designed to support and be available for a maximum mission frequency. High flight rates are desirable to ensure crew proficiency and to provide adequate testing opportunities supporting future Mars missions.

TBR Closure: Additional data to support budget and funding profiles will be developed during the CE&R studies. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

**ESS0190** The Exploration System of Systems shall provide a minimum of 1 lunar mission opportunity per month (**TBR-8**).

*Rationale* : A mission opportunity is the time window for departure from the Earth vicinity to the Moon. Although budgets and operational factors will drive the frequency of missions, it is important that the program not be restricted to a small number of mission opportunities per year.

This requirement sets the minimum rate for mission opportunities along with its associated potential contingency rescue mission. Specific architecture choices could severely limit mission opportunities and therefore would be eliminated by this requirement. This requirement does not imply that the ESS will be able to actually execute a mission every month, nor does it imply that all launches to support a single

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mission must occur within a one month period.

Frequent mission opportunities are important, to allow sufficient recovery options, should a given mission opportunity be missed.

TBR Closure: Additional data to support budget and funding profiles will be developed during the CE&R studies. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

**ESS0200** The Exploration System of Systems shall conduct robotic missions to lunar orbit, lunar vicinity, and the lunar surface in support of human exploration.

*Rationale* : Robotic missions to the Moon are likely to continue in Spiral 2. With the capability to deliver humans to any site of interest on the moon, robotic missions can identify specific areas for human exploration, and integrated robotic and human exploration missions may be undertaken.

**ESS0210** The Exploration System of Systems shall conduct Robotic Precursor Missions to Martian orbit, Martian vicinity, and the surface of Mars to prepare for future human exploration.

*Rationale* : Further definition of the Spiral. Direct flow-down from Level 0 requirements.

### 3.2.3 Exploration Spiral 3 (S3)

**ESS0230** The Exploration System of Systems shall conduct human lunar exploration missions to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources, to support sustained human space exploration to Mars and other destinations.

*Rationale* : This requirement is a flow-down of Level 0 Exploration Requirement (1.3) “NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations.” Demonstration of key systems, technologies, and operational approaches that are applicable for Mars exploration are Spiral 3 primary objectives.

**ESS0240** The Exploration System of Systems shall conduct human lunar exploration missions to further science.

*Rationale* : This requirement is a flow-down of Level 0 Exploration Requirement (1.3) “NASA shall conduct human lunar expeditions to further science, and to develop and test new exploration approaches, technologies, and systems, including the use of lunar and other space resources to support sustained human space exploration to Mars and other destinations.” This requirement captures the science objective of exploration.

**ESS0250** The Exploration System of Systems shall conduct human exploration on the lunar surface with a threshold of 4 crew members, and an objective of 6 crew members (**TBR-15**).

*Rationale* : A 4 person crew is the minimum number required to demonstrate operations concepts for exploring more distant destinations such as Mars. A 4 person crew (threshold) allows two EVA teams (2 crew per team) to operate simultaneously or in series while providing the capability for operational assistance from the non-EVA crew. A 6 person crew (objective) represents the most likely Mars

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exploration crew size, based on previous studies. However, since human rated launch capability is likely to be a limiting factor on CEV capability, 6 person crew size is carried as an objective only. Lower level requirements for each element will specify the capability to operate with fewer than 4 or 6 crew. Human exploration includes the use of robotic elements as part of the system.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results", ESMD-RQ-0016, "STTP-2 Meeting Minutes."

TBR-15 Closure: Further surface scenario assessments are required during the CE&R study phase. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

**ESS0260** The Exploration System of Systems shall conduct long-duration human exploration missions with a surface duration (threshold) of 42 days (**TBR-3**), and an objective of 98 days (**TBR-4**) to any designated location in the polar or equatorial regions (**TBR-17**) of the Moon.

*Rationale* : Long-duration missions are required to test operational concepts and systems for future Mars exploration. These long duration missions will require establishing a lunar base with surface infrastructure such as habitats, surface power systems, etc. The location for this lunar base will depend on the results of the early robotic precursor missions in Spiral 1, with the south pole and the equator as the most promising regions. Surface durations for opposition class Mars missions range from 30-90 days depending on the mission opportunity and propulsion technology employed. Lunar surface testing of operational concepts involves mission planning for exploration activities over a similar period. The day-night cycle on Mars is similar to Earth. However, on the Moon, 14 days of light are followed by 14 days of dark. The threshold duration allows for 2 day cycles and 1 night cycle. The objective duration is similar to a typical Mars short stay mission and allows for 4 day cycles and 3 night cycles. The primary objectives are demonstration of technologies and operational concepts, and science.

References: ESMD-RQ-0005, "Lunar Architecture Focused Trade Study Final Results", ESMD-RQ-0006, "Lunar Architecture Broad Trade Study Final Results", ESMD-RQ-0016, "STTP-2 Meeting Minutes."

TBR Closure: Surface stay durations will be defined once the launch strategy is defined and during further assessments of the surface element design activities. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

**ESS0280** The Exploration System of Systems shall provide a minimum flight rate capability of 1 human exploration mission to the lunar surface per year (**TBR-9**) .

*Rationale* : This requirement is a flow-down of Level 0 Requirements (1) calling for "a safe, sustained, and affordable robotic and human program."

The Exploration System of Systems must be designed to support and be available for a minimum mission frequency in order to provide a sustainable Exploration program. Spiral and mission objectives must be achieved efficiently in order to achieve the challenging Level 0 milestones set for human exploration of the Moon, and ultimately Mars. A minimum flight rate should also be sufficient to support efforts to maintain flight and ground crew proficiency.

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TBR-9 Closure: Additional data to support budget and funding profiles will be developed during the CE&R studies. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

**ESS0285** The Exploration System of Systems shall have the capability to deliver cargo to the lunar surface.

*Rationale :* This requirement expresses the need for delivery of uncrewed payloads to the lunar surface. This capability will be needed to pre-deploy Destination Surface System assets (e.g., Habitation Module, Surface Power System) for use during human lunar exploration missions. This requirement will serve as a parent for the Cargo Delivery System.

**ESS0290** The Exploration System of Systems shall provide a maximum flight rate capability of **(TBD-4)** human exploration missions to the lunar surface per year.

*Rationale :* Budgets are likely to determine the actual frequency of missions. However, the system must be designed to support and be available for a maximum mission frequency. High flight rates are desirable to ensure crew proficiency and to provide adequate testing opportunities supporting future Mars missions.

TBD-4 Closure: Additional data to support budget and funding profiles will be developed during the CE&R studies. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

**ESS0300** The Exploration System of Systems shall provide a minimum of 1 lunar mission opportunity per month **(TBR-11)**.

*Rationale :* Although budgets and operational factors will determine the actual frequency of missions, it is important that the program not be restricted to a small number of mission opportunities. This requirement sets the minimum rate for mission opportunities along with an associated potential contingency rescue mission. Specific architecture choices could severely limit mission opportunities and therefore would be eliminated by this requirement.

TBR-11 Closure: Additional data to support budget and funding profiles will be developed during the CE&R studies. This issue will be resolved no later than 90 days prior to the CEV System Requirements Review.

**ESS0310** The Exploration System of Systems shall conduct robotic missions to lunar orbit, lunar vicinity, and the lunar surface in support of human exploration.

*Rationale :* Robotic missions to the Moon are likely to continue in Spiral 3. With the capability to deliver humans to any site of interest on the moon, robotic missions can identify specific areas for human exploration, and integrated robotic and human exploration missions may be undertaken.

**ESS0320** The Exploration System of Systems shall conduct Robotic Precursor Missions to Martian orbit, Martian vicinity, and the surface of Mars to prepare for future human exploration.

*Rationale :* Further definition of the Spiral. Direct flow-down from Level 0 requirements.

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### 3.3 NASA Procedural Requirements (NPRs)

**ESS0340** The Human elements of the Exploration System of Systems shall comply with NPR 8705.2, Human-Rating Requirements and Guidelines for Space Flight Systems

*Rationale :* NPRs are agency level requirements and not at the discretion of the Directorate.

In order to fly humans in space, each element of the System of Systems that interfaces with the crew must be certified as human rated. NPR 8705.2 delineates the requirements and process for obtaining that certification and is applicable to those elements that interact with the crew.

The current version is NPR 8705.2 with Change 2 dated 6/25/04. The document is currently under review and a new approved version is expected prior to release of the CEV RFP.

**ESS0350** The Exploration System of Systems shall comply with NPR 8715.3, NASA Safety Manual.

*Rationale :* NPRs are agency level requirements and not at the discretion of the Directorate.

This document contains the requirements and procedures for NASA Safety Programs to minimize risk to personnel and equipment.

**ESS0370** The Exploration System of Systems shall comply with NPR 7150, NASA Software Engineering Requirements.

*Rationale :* NPRs are agency level requirements and not at the discretion of the Directorate. Specific version and dates shall be identified in the spiral requirements.

**ESS0380** The Exploration System of Systems, when launching from U.S. Ranges, shall comply with NPR 8715.x (**TBD-65**), NASA Range Safety Program.

*Rationale :* NPRs are agency level requirements and not at the discretion of the Directorate.

Space systems launched from U.S. ranges are required to comply with Air Force Range Requirements as tailored for the system. The Range Safety NPR will contain the NASA tailored requirements to launch on U.S. Ranges.

TBD Closure: This NPR is currently in the NODIS review cycle; approval is expected in early 2005.

**ESS0390** The Exploration System of Systems shall comply with NPR 8020.12, Planetary Protection Provisions for Robotic Extraterrestrial Missions, for all Mars Robotic Precursor missions.

*Rationale :* NPR 8020.12 sets forth requirements applicable to robotic planetary flight programs. These requirements are necessary to satisfy the NASA responsibilities outlined in NPD 8020.7, Biological Contamination Control for Outbound and Inbound Planetary Spacecraft. This document is specifically directed to (1) the control of terrestrial microbial contamination associated with robotic space vehicles intended to land, orbit, flyby, or otherwise be in the vicinity of extraterrestrial Solar System bodies, and (2) the control of contamination of the Earth and Moon by extraterrestrial Solar System material collected and returned by such missions. Lunar missions are specifically excluded from compliance with NPR 8020.12. Applicability to Human-Mars missions will be addressed in requirements for Exploration Spiral 4 and beyond.

**ESS0650** The Exploration System of Systems shall dispose of expendable flight elements at end of life in accordance with NPD 8710.3, NASA Policy for Limiting Orbital Debris Generation.

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*Rationale* : Disposal of any flight hardware that may generate orbital debris in Earth orbit, or may reenter the Earth's atmosphere are governed by this NPD. Abort towers, ascent stages, and earth departure stages are examples of potential flight hardware covered by this NPD.

**ESS0360** The Exploration System of Systems shall comply with NASA-STD-8719.13, Software Safety Standard, for all Safety-Critical Software.

*Rationale* : Software is a critical component of all complex space systems. Safety Critical Software (as defined in NASA-STD-8719.13) must be developed and tested to ensure the safety of the crew. The definition of Safety Critical Software is also contained in the requirements glossary. Although 8719.13 is a standards document, it contains specific software requirements.

## 4 Appendices

### 4.1 Glossary

**Abort** Termination of the nominal mission that allows the crew to be returned to Earth in the portion of the space system used for nominal reentry and touchdown (see Abort to Earth, Abort to Orbit).

**Abort to Earth** Early mission termination, with direct return to the Earth's surface as the immediate objective.

**Abort to Orbit** An early mission termination that has an immediate objective of placing a crewed flight system in Earth (or destination vicinity) orbit, prior to return to the Earth's surface.

**Annunciate** To provide a visual, tactile or audible indication.

**Ascent** The function of liftoff from the Earth (or mission destination) surface, to spacecraft insertion into Earth/destination orbit.

**Automated control** Automatic, as opposed to human operation or control of a process, equipment or a system; or the techniques and equipment used to achieve this. Automation is the control or execution of actions with no human interaction. Automated control does not exclude the capability for manual intervention / commanding, but manual intervention / commanding is explicitly not required to accomplish the function.

**Autonomous experiments** Defined as a flight experiments operating independent of external commands or control (i.e. commands from mission control on Earth). Autonomous experiments can be fully automated or require some degree of manual commanding/intervention.

**Autonomous operations** Defined as a flight vehicle operating independent of external communication, commands or control (i.e., commands from mission control on Earth). Autonomous operations can be fully automated or require some degree of manual commanding/intervention by the onboard crew. Autonomous operations that do not require onboard crew involvement are, by definition, automated; therefore, the term "autonomous operations" used in the requirements assumes onboard crew involvement in the operations.



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**Berthing** A method of mating two or more Exploration elements in space. During a berthing operation, the two elements are mechanically connected prior to the structural capture and final mating (i.e., one element grapples the other with a robotic arm). One element controls the trajectory and attitude of the other element for the contact and capture. Final mating is generally performed by the berthing mechanism (also see docking).

**Cargo Delivery System (CDS)** The CDS encompasses the capability to deliver all non-CEV flight elements needed to accomplish human exploration objectives. At such time as CDS elements dock with the CEV, they are part of a human crew occupied system, and are considered part of the CTS.

**Cargo Launch Vehicle** The Cargo Launch Vehicle is an element of the Cargo Delivery System. The Cargo Launch Vehicle will perform the ascent function for non-crewed elements of the CTS (EDS, LSAM), into an Earth Orbit. Since the Cargo Launch Vehicle will not carry human crew, it will not require Human-Rating.

**Catastrophic Hazard** A condition that may cause death or permanently disabling injury, major system or facility destruction on the ground, or major systems or vehicle destruction during the mission. (From NPR 8715.3 Safety Manual)

**Consumables** Resources that are consumed in the course of conducting a given mission. Includes propellant, power, habitability items (e.g., gaseous oxygen), and crew supplies.

**Contingency EVA Capability** An EVA capability provided to deal with critical failures or circumstances, which are not adequately protected by redundancy or other means.

**Crew Exploration Vehicle (CEV)** The CEV provides crew habitation and Earth reentry capability for all Exploration Spirals.

**Crew Exploration Vehicle Launch Segment (CEVLS)** The CEVLS consists of a Crew Exploration Vehicle (CEV), a Crew Launch Vehicle (CLV), and all the dedicated ground support infrastructure necessary to launch the CEV to Earth orbit.

**Crew Launch Vehicle (CLV)** The CLV is an element of the CTS. The CLV will be human-rated, and will deliver the CEV into a mission-specific Earth Ascent Target Orbit.

**Crew Member** Human onboard the spacecraft or space system during a mission.

**Crew Survival** Capabilities designed to keep the crew alive through means such as abort, escape, safe haven, emergency egress, and rescue in response to a Catastrophic Hazard.

**Crew Transportation System (CTS)** The CTS encompasses the flight elements needed to deliver a human crew from Earth to a mission destination, and return the crew safely to Earth. The CTS must interact with the Ground Support System (GSS) during all Spirals; current architectures require delivery of the EDS and LSAM to Earth orbit through use of the CDS.

**Critical Hazard** A condition that may cause a severe injury or occupational illness, loss of mission, or

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major property damage to facilities, systems, or flight hardware.

**Day** Defined as an Earth day of 24 hours.

**Destination Surface System (DSS)** The DSS encompasses all elements (exclusive of the surface lander that transports the crew to the destination surface) necessary to enable a long-duration human exploration mission. Examples of DSS elements include a long-duration habitation module, surface power capability, and surface transportation systems. DSS elements will be delivered to the destination surface via the CDS. It is likely that these assets will be pre-deployed in advance of the crew that will utilize them to execute a given Exploration mission.

**Destination Surface to Destination Vicinity Phase** Starts with the initiation of the ascent (T0) from the destination surface. Representative mission activities include: ascent, abort, and orbit insertion or libration capture. Phase ends after successful destination vicinity insertion/capture.

**Destination Vicinity Operations Phase (A)** Starts at the successful insertion/capture at the destination vicinity. Representative mission activities include: loiter and phasing, vehicle and system checkout, crew-cargo transfers, undocking and separation. Phase ends at the successful separation of surface lander system for descent burn.

**Destination Vicinity Operations Phase (B)** Starts after the successful destination orbit insertion or libration point capture, following ascent from destination surface. Representative mission activities include: phasing, vehicle-system checkout, crew-cargo transfer, undocking and separation maneuver, element disposal and/or safing. Phase ends at the completion of the Trans-Earth Injection burn.

**Destination Vicinity to Earth Phase** Begins with completion of Trans-Earth Injection burn and includes mid-course corrections, cruise to Earth vicinity, element separation and element disposal. Ends with arrival at Earth entry interface or insertion to Earth orbit.

**Destination Vicinity to Destination Surface Phase** Starts at the initiation of the descent burn from destination vicinity (destination deorbit burn or libration departure burn to destination). Representative mission activities include: descent to destination surface, descent aborts, landing, propulsion system shutdown and safing. For libration architectures, additional activities include orbit capture, phasing, and de-orbit maneuvers. Phase ends when the vehicle has completed all landing activities on the destination surface, including propulsion system shutdown and safing.

**Docking** A method of mating two or more Exploration elements in space. In a docking operation, the structural mechanisms are brought into contact and captured through independent control of the two vehicles' flight path and attitude. Final mating is generally accomplished by the docking mechanism (also see Berthing).

**Earth Ascent Target Orbit** The planned orbit, at conclusion of the ascent function.

**Earth Departure Stage (EDS)** EDS will be used to provide the propulsive force needed to transfer the various flight elements to destination phasing orbits (including the CEV and LSAM).

**Earth-Moon Transit** Transit of a spacecraft between Earth vicinity and Lunar vicinity in either

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direction.

**Earth Orbit Operations Phase (A)** Starts with completion of Earth orbit insertion. Representative activities include: phasing, rendezvous, docking and loiter. Ends with completion of a burn to leave Earth orbit (i.e., Trans-Lunar Injection burn or de-orbit burn).

**Earth Orbit to Destination Vicinity Phase** Starts after completion of vehicle injection burn (i.e., Trans-Lunar Injection) and includes mid-course corrections, element separation/disposal, and cruise to destination vicinity. Ends with successful insertion/capture at destination vicinity.

**Earth to Orbit Phase** Starts with liftoff. Representative activities include liftoff through ascent to orbit, ascent crew escape/abort and re-entry/descent during aborts, disposal of elements. Ends with insertion into a stable, 24 hour Earth orbit (i.e., at least 24-hour stability) or return to Earth (in the event of an abort).

**Earth Re-entry Phase** Direct re-entry returns from beyond Earth orbit begin with arrival at Earth entry interface; Earth-orbit Aerocapture return begins with completion of Earth orbit injection. In either case, phase includes descent through the atmosphere and ends with landing on the Earth's surface. This phase encompasses activities necessary to successfully execute direct-to-Earth aborts during ascent and direct entry return from beyond Earth orbit.

**Earth Reference Orbit** The orbit designated for assembly of Exploration System elements prior to departure for exploration destinations, defined by the following parameters: Inclination: 28.5-29.0 degrees; Launch Azimuth: 90+/- 5 degrees; Altitude: 307 km - 407 km.

**Element** A set of functional capabilities necessary to satisfy system-level mission objectives within a given architecture. CTS elements currently include the Crew Exploration Vehicle, Earth Departure Stage, and Lunar Surface Access Module. Elements can perform all system functions within a mission phase, or through mated operations with other exploration elements (as part of a segment).

**Emergency Egress** The timely and unassisted crew exit of a vehicle (i.e., in response to a Catastrophic Hazard).

**Entry footprint** Region on Earth's surface defined by the boundaries of the Earth entry corridor for a given vehicle.

**Equatorial Region of the Moon** Defined as the area between 0-20 degrees lunar latitude (threshold), with an objective of 0-30 degrees (**TBR-7**).

**Escape** Removal of crew from the failing spacecraft, due to an imminent catastrophic condition, thus placing them in a safe situation suitable for survivable return to Earth and rescue. Escape includes, but is not limited to, those capabilities that utilize a portion of the original space system for the removal (e.g., escape pods).

**Exploration Spiral 1 (Crew Exploration Development and Test)** Encompasses the capabilities necessary to insert humans into Earth orbit and return them safely to Earth, employing a post-Space Shuttle flight system. The flight elements of the Exploration Spiral 1 Crew Transportation System are the

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Crew Exploration Vehicle and Crew Launch Vehicle. Robotic Precursor Missions that are scheduled to launch prior to the Earth orbit demonstration of the Spiral 1 CTS are considered Exploration Spiral 1 missions.

**Exploration Spiral 2 (Global Lunar Access for Human Exploration)** Encompasses the capabilities necessary to execute human lunar exploration anywhere on the surface of the moon. Lunar global access exploration missions will be 4-7 days in duration on the lunar surface, and do not require pre-deployed surface systems (e.g., Habitation Module or Surface Power). Robotic Precursor Missions scheduled to launch after the Spiral 1 CTS flight demonstration, and prior to the first Spiral 3 Lunar mission are considered Exploration Spiral 2 missions.

**Exploration Spiral 3 (Lunar Base and Mars Testbed)** Encompasses the capabilities necessary to execute a long-duration human lunar exploration campaign. This campaign requires development of extensive surface systems (e.g., habitation and surface power system). Robotic Precursor Missions that are scheduled to launch after the last Spiral 2 extended- duration lunar mission, and prior to the initial Exploration Spiral 4 mission are considered Exploration Spiral 3 missions.

**Extended-Duration (Lunar Mission)** Human missions to the lunar surface ranging from 4 days (96 hours) through 7 days. This capability is an objective of Exploration Spiral 2. Extended-duration lunar missions do not require pre-deployed Surface Systems (e.g., habitation modules or surface power system).

**Extra-Vehicular Activity (EVA)** Operations performed by crew members outside the pressurized environment of a flight vehicle or habitat (during space flight or on a destination surface).

**Failure Tolerance** Failure tolerance is a term used to describe minimum acceptable redundancy. It may also be used to describe similar systems, dissimilar systems, cross-strapping, or functional interrelationships that ensure minimally acceptable system performance despite failures. It is highly desirable that space flight systems performance degrades in a predictable fashion that allows sufficient time for failure detection and, when possible, system recovery even when experiencing multiple failures.

**Genomics** Genetic mapping and DNA sequencing of genes, with applications of the data in medicine or biology.

**Geodetic** Referenced to the global center of mass of any body (does not refer only to the Earth).

**Ground Operations Phase** Begins with the start of mission planning. Representative activities include: mission planning, training, receipt of government hardware/software, acceptance, test, checkout, repair, inspection, assembly, integration, servicing and countdown activities. Also includes ground contingency, emergency, abort and turnaround operations. Phase ends with vehicle liftoff.

**Ground Support System** This system provides all common ground-based capabilities (e.g., mission control, launch-site processing) needed to execute Exploration missions. Facilities and capabilities that are unique to a single Exploration System, such as the CTS, will be included as part of the system it supports.

**Guidance and Control** The process of directing the movements of a space vehicle, including selection of a flight path and making changes in attitude and speed.

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**Habitation** The provision for and management of the crew environment (i.e., through the use of life support systems, thermal control, etc.) in a crewed vehicle or habitat.

**In-Space Support System (IS<sup>3</sup>)** Encompass capabilities provided by space-based infrastructure elements (e.g., communications, navigation, surveillance), that are placed in orbital or lunar/planetary locations, and their corresponding ground-based operation (e.g., a ground station or antenna). These capabilities are exclusive of those provided by elements of the DSS.

**Inclination** The angle between the plane of an orbit and a reference plane, most frequently the equator of the central body (e.g., the Earth's equator for geocentric orbits).

**Independent Technical Authority (ITA)** A responsibility owned by the NASA Chief Engineer, which is then delegated through the issuance of warrants. A warrant holder is designated as compliance officer over an identified set of engineering and technical requirements or standards.

**Initial Lunar Phasing Orbit** Used in Spiral 2 and 3 to define the orbit from which the CEV will assume delta V responsibility for inbound rendezvous and docking with the LSAM in lunar orbit. Defined by the following parameters: Altitude: 100 km x 500 km +/- (TBD-6) km (TBR-34); Maximum inclination error with respect to the Lunar Reference Orbit; 0.5 degrees (TBR-28).

**Initial Operational Capability (IOC)** The capability achieved when an element, segment, or system (e.g., the CEVLS) passes its initial Flight Readiness Review in connection with a given Exploration Spiral.

**Integrated Logistics Support (ILS)** Is an approach that enables disciplined, unified and iterative management of support considerations into system and equipment design. ILS includes development of support requirements that are related to readiness objectives, to design, and to each other. Requirements in turn drive acquisition of required support; ILS is then employed during the operational phase.

**Launch Availability** The likelihood that a given launch will be achieved without a scrub once the mission timeline (first element launch for a multiple launch mission) or the launch countdown call to stations (for a mission scenario involving a single launch) has commenced. Launch availability is composed of four elements: system availability, launch probability, launch site weather constraints and abort weather constraints. Launch Availability can be expressed as:  $P(LA) = P(SA) \times P(LP) \times P(LW) \times P(AW)$

Where:

P(LA) = Launch Availability (overall probability of achieving a launch)

P(SA) = System Availability (probability of hardware being acceptable for launch)

P(LP) = Launch Probability (probability that the vehicle limits are not violated by upper level winds or other natural environment phenomena)

P(LW) = Launch Weather (probability that other launch site weather constraints are not violated)

P(AW) = Abort Weather (probability that abort weather constraints are not violated)

**Launch Azimuth** The angle formed by the projection of the flight path of the launch vehicle onto the surface of the earth's ellipsoid and the North direction, measured clockwise in degrees.

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**Launch Opportunity** The period of time during which the relative position of the launch site and orbital plane permit a launch vehicle to perform the ascent function.

**Life Support** A subset of crewed vehicle (or habitat) habitation functions (i.e., a subsystem) that provides and manages breathable air, contamination control, potable water, fire detection/suppression, cabin pressure/temperature/humidity, environmental monitoring, etc.

**Long-Duration (Lunar Mission)** Human missions to the lunar surface that require pre-deployed Surface Systems. This capability is a requirement in Exploration Spiral 3, and encompasses surface stays from 42 days (threshold) (**TBR-3**) up to 98 days (objective) (**TBR-70**).

**Low Earth Orbit (LEO)** An orbit around the Earth with a minimum orbital altitude of 170 km and is a stable orbit that will not decay rapidly because of atmospheric drag.

**Lunar Architecture Focused Trade Study** Ongoing engineering analysis of lunar architecture and mission design options, in support of Exploration architecture decision-making. Results of this study are captured in document ESMD-RQ-0005, “Lunar Architecture Focused Trade Study Final Results”.

**Lunar Ascent Orbit** Used in Exploration Spirals 2 and 3 to define the orbit that the LSAM must achieve when launching from the lunar surface. Defined by the following parameters: Altitude: 100 km +/- (**TBD-8**) km; Inclination angle (wedge angle) with respect to Lunar Reference Orbit: Maximum of 10 degrees (**TBR-71**).

**Lunar Day** The period of time it takes for the Moon to make one complete orbit around the Earth, due to tidal locking. It is marked from a New Moon to the next New Moon. A lunar day is officially 29 days, 12 hours, 44 minutes and 3 seconds long.

**Lunar Reference Orbit** Used in Exploration Spirals 2 and 3 to define the lunar orbit for rendezvous and docking of Exploration elements. Defined by the following parameters: Altitude: 100 km +/- (**TBD-8**) km; Inclination: Optimized for the mission.

**Lunar Surface Access Module (LSAM)** Provides crew transport to the lunar surface from the Lunar Reference Orbit and return from the surface to the Lunar Ascent Orbit; also provides limited surface habitation and EVA capabilities.

**Mating** The act of mechanically connecting together two major elements of a system. Mating can be performed in space, through docking or berthing, or on the ground through docking, berthing, or other interfaces.

**Mission** Refers to the sequence of events that must take place to accomplish prescribed scientific, technological, or engineering objective(s). Includes transportation of a flight system (robotic or human-crewed) to a destination, and operational activities at the destination (e.g., the Martian surface).

**Mission Capable** Refers to the status of an Exploration flight element or mated elements, which have sufficient consumables to fully execute its intended mission from its current location in space.

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**Mission Opportunity** Refers to the Earth departure window to conduct a mission to another planetary destination such as the Moon or Mars. Typically constrained by orbital mechanics and the design of the Exploration System. If assembly of elements in Earth orbit is required, then "Mission Opportunity" refers to the departure window from Earth orbit based on the capability of the Exploration System.

**Mission Phase Definitions** Used as the basis for functional flow and decomposition of reference Spiral 3 human exploration mission. The Mission Phases identified were Ground Operations, Earth to Orbit, Earth Orbit Operations, Earth Orbit to Destination Vicinity, Destination Vicinity Operations (A), Destination Vicinity to Surface, Surface Operations, Destination Surface to Destination Vicinity, Destination Vicinity Operations (B), Destination Vicinity to Earth, Earth Reentry, and Recovery (see associated definitions).

**Net Habitable Volume** The functional pressurized volume left available to the crew after accounting for the loss of volume due to deployed equipment, stowage, trash, and any other items which decrease functional volume. The gravity environment corresponding to the habitable volume must be specified.

**Objective** Used in requirements language to define the desired capability above the threshold that should be evaluated for feasibility and affordability. Capabilities above the objective are not expected to be pursued or analyzed.

**Payload** The onboard scientific and exploration utilization (i.e. ISRU) equipment carried by a given spacecraft, generally quantified in terms of mass and volume. Also expressed as the entire mass delivered by a launch vehicle, to orbit.

**Polar Regions of the Moon** Defined as the area between 80-90 degrees (**TBR-74**) lunar latitude (threshold), with an objective of 70-90 degrees (**TBR-76**).

**Probabilistic Risk Assessment** A comprehensive, structured, and logical analysis methodology employed to identify and assess risks in technologically complex systems. Probabilistic Risk Assessment results can be used to develop or validate Fault Trees and Failure Modes analysis. They also can be used as a tool for making design and logistics decisions.

**Proteomics** Analyzing structure, function, and interactions of the proteins produced by the genes of a particular cell, tissue or organism, with applications of the data to medicine or biology.

**Proximity Operations** Phase of flight operations (near the end of rendezvous and prior to docking; or after undocking) during which two space vehicles are at close ranges (< 1 km) and low relative velocity.

**Recovery Phase** Begins with completion of Earth surface landing and includes recovery forces operations, vehicle safing, vehicle configuration for recovery, crew egress, crew return to post-mission facilities. Ends with vehicle recovery to post-mission facilities for refurbishment or disposal.

**Regolith** Fine-grained powdery layer on the lunar surface above the bedrock.

**Remotely Commanded Operations** The capability to operate a vehicle, system, or subsystem from an external location (e.g., mission control). Remotely commanded operations do not require the presence of an onboard crew.

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**Rescue** The process of locating the crew, proceeding to their position, and transporting them to an appropriate location.

**Robotic Precursor Mission** A robotic spacecraft mission that supports The Vision by achieving scientific objectives and/or through preparing for future human exploration activities.

**Robotic Precursor Phase** Exploration missions accomplished by robotic systems, to prepare for and support future human exploration missions.

**Robotic Precursor System** Robotic spacecraft that are developed to execute missions that prepare for and support future human exploration, and to accomplish science objectives.

**Safety-Critical Software** Software is safety-critical if it meets at least one of the following criteria:  
1. Resides in a safety-critical system (as determined by a hazard analysis AND at least one of the following:

- a. Causes or contributes to a hazard.
- b. Provides control or mitigation for hazards.
- c. Controls safety-critical functions.
- d. Processes safety-critical commands or data.
- e. Detects and reports, or takes corrective action, if system reaches hazardous state.
- f. Mitigates damage if a hazard occurs.
- g. Resides on the same system (processor) as safety-critical software.

2. Processes data or analyzes trends that lead directly to safety decisions (e.g., determining when to turn power off to a wind tunnel to prevent system destruction.)

3. Provides full or partial verification or validation of safety-critical systems, including hardware or software subsystems.

**Segment** Used in the CTS requirements development process to express the identity of two or more elements mated together and operating jointly in a given set of mission phases. Segments defined this way facilitate functional decomposition of capabilities throughout the reference Exploration Spiral 3 mission. For example, the In-Space Transportation Segment is comprised of the CEV and an Earth Departure Stage, and comprises the CTS from the Earth Orbit Operations Mission Phase until CEV-EDS separation during the Destination Vicinity Operations Mission Phase. Other segments were defined as the CEV Launch Segment (CEV and CLV operating through separation in Earth orbit), the Destination Transportation Segment (CEV and LSAM operating in the lunar vicinity), and the Earth Return Segment (CEV only, upon separation from LSAM Ascent Stage).

**Spiral Development Process** A phased system of systems development process that allows increasing capabilities to be achieved in support of long range objectives. While work can be accomplished concurrently against the objectives associated with multiple spirals, the completion of all objectives for a given spiral is considered necessary to enable achievement of the succeeding spiral. See associated definitions for Exploration Spirals.

**Strategy to Task to Technology Process (STTP)** Use of engineering analysis to validate architectural and mission design approaches, and identify technology investment needs.



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**Surface Operations Phase** Starts at the completion of landing on the destination surface, including propulsion system shutdown and safing. Representative mission activities include: science operations, system and operational testing, surface EVA, assembly and maintenance, vehicle checkout, and preparation for ascent. Phase ends at initiation of ascent from the destination surface (i.e., T0).

**System** A set or arrangement of interdependent elements/segments that are used to accomplish mission objective(s). Exploration systems are Crew Transportation, Cargo Delivery, In-Space Support, Destination Surface, Robotic Precursor, and Ground Support. These systems comprise the Exploration System of Systems.

**System of Systems** A set or arrangement of interdependent systems that are related or connected to provide a given capability. The loss of any portion of the System of Systems will degrade the performance or capabilities of the whole. The systems contained in the Exploration System of Systems (ESS) are: the Crew Transportation System, Cargo Delivery System, In-Space Support System, Destination Surface System, Robotic Precursor System, and Ground Support System. Requirements, constraints, and guidelines that apply to all human and robotic exploration systems are levied against the Exploration System of Systems, and may apply against any or all Exploration Spirals, as specified. The term “System of Systems” is sometimes expressed synonymously as “Super-system”.

**Threshold** Used in requirements language to define the minimum capability necessary to satisfy the requirement.

**Transfer Volume** The passageway between two connected element that can contain crew.

**Wedge Angle** The angle existing between two orbital planes. A plane change maneuver must be accomplished (i.e., through the use of delta-V capability) to negotiate the wedge angle between a given initial orbit plane (e.g., the Earth Reference Orbit) and a desired target orbital plane (e.g., the Lunar Reference Orbit).

## 4.2 Acronyms

AIM	Advanced Integrated Matrix
AO	Announcement of Opportunity
CDS	Cargo Delivery System
CE&R	Concept Exploration and Refinement
CEV	Crew Exploration Vehicle
CEVLS	Crew Exploration Vehicle Launch Segment
CLV	Crew Launch Vehicle
CG	Center of Gravity
CTS	Crew Transportation System
DSN	Deep Space Network
DSS	Destination Surface System
EDS	Earth Departure Stage
EI	Entry Interface
ECLSS	Environmental Control/Life Support System
ESMD	Exploration Systems Mission Directorate

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ESS	Exploration System of Systems
EVA	Extra-Vehicular Activity
FOM	Figures-of-Merit
GCR	Galactic Cosmic Ray
GN&C	Guidance, Navigation, and Control
GSS	Ground Support System
HR&T	Human & Robotic Technology
INSTEP	In-Space Technology Experiments Program
IOC	Initial Operational Capability
IRD	Interface Requirements Document
ILS	Integrated Logistics Support
IS <sup>3</sup>	In-Space Support System
ISRU	In-Situ Resource Utilization
ITA	Independent Technical Authority
JIMO	Jupiter Icy Moon Orbiter
KPP	Key Performance Parameters
LAWG	Lunar Architecture Working Group
LEO	Low Earth Orbit
LExSWG	Lunar Exploration Science Working Group
LRL	Lunar Robotic Lander
LRO	Lunar Robotic Orbiter
LSAM	Lunar Surface Access Module
LSI	Landed Surface Interrogator
MEPAG	Mars Exploration Program Analysis Group
NEDD	Natural Environments Definition for Design
NODIS	NASA Online Directives Information System
NP	NASA Publication
NPD	NASA Policy Documents
NPR	NASA Procedural Requirement (Document)
OAG	Operations Advisory Group
ORDT	Objectives and Requirements Definition Team
OSMA	Office of Safety and Mission Assurance
OSP	Orbital Space Plane
PDR	Preliminary Design Review
PDS	Planetary Data System
PRA	Probabilistic Risk Assessment
RFP	Request for Proposals
RLEP	Robotic Lunar Exploration Program
RPS	Robotic Precursor System
SMD	Science Mission Directorate
SPE	Solar Particle Event
SRR	System Requirements Review
STD	Standard (Document)
STTP	Strategy to Task to Technology Process (or Panel)
TBD	To Be Determined
TBR	To Be Resolved

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TPS        Thermal Protection System  
TRL        Technology Readiness Level

### 4.3 Requirements Taxonomy

The following table is provided as a key to understanding the taxonomy used for requirement Unique ID numbers (i.e., the Unique ID number is shown at the beginning of each requirement statement).

<b>S y s t e m / S e g m e n t</b>	<b>R e q . N u m b e r</b>	<b>S p i r a l</b>
<b>E S S</b> ( E x p l o r a t i o n   S y s t e m   o f   S y s t e m s   T e c h n i c a l )	<b>0 0 0 1 - 9 9 9 9</b>	<b>A = S p i r a l 1</b>
<b>E P R</b> ( E x p l o r a t i o n   P r o g r a m m a t i c   R e q u i r e m e n t s )		<b>B = S p i r a l 2</b>
<b>E P G</b> ( E x p l o r a t i o n   P r o g r a m m a t i c   G u i d e l i n e s )		<b>C = S p i r a l 3</b>
<b>C T S</b> ( C r e w   T r a n s p o r t a t i o n   S y s t e m )		<b>D = S p i r a l 4</b>
<b>C V S</b> ( C E V   L a u n c h   S e g m e n t )		<b>E = S p i r a l 5</b>
<b>C E V</b> ( C r e w   E x p l o r a t i o n   V e h i c l e )		<b>F = S p i r a l s 1 &amp; 2</b>
<b>C V L</b> ( C E V   L a u n c h   V e h i c l e )		<b>G = S p i r a l s 2 &amp; 3</b>
		<b>H = S p i r a l s 1,2,3</b>

### 4.4 Requirements Traceability Table

The following traceability table provides a summary of parent-child traceability from SA-0001, The Level 0 Exploration Requirements for NASA (dated May 4, 2004) to the ESS Technical Requirements Document (ESMD-RQ-0010).

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Level 0 Parent	ESS Child
3.0 (1.1) 2.0 (1) 2.0 (1.2)	ESS0010
2.0 (1) 2.0 (1.4)	
2.0 (1)	
2.0 (1)	ESS0020
2.0 (1)	ESS0030
3.0 (1.2) 2.0 (1) 2.0 (1.3)	ESS0040
2.0 (1) 2.0 (1.5)	
2.0 (1)	
2.0 (1.1)	ESS0070
3.0 (1.3)	ESS0080
2.0 (6)	ESS0090
3.0 (3)	ESS0100
2.0 (1.2)	ESS0110
2.0 (1.3)	ESS0120
2.0 (1.3)	ESS0130
2.0 (1.3)	ESS0150
2.0 (1.3) 2.0 (1.5)	ESS0160
2.0 (1) 2.0 (1.5) 2.0 (1.3)	
2.0 (1)	ESS0170
2.0 (1)	ESS0180
2.0 (1) 2.0 (1.5) 2.0 (1.3)	ESS0190
2.0 (1.2)	
2.0 (1.4)	
2.0 (1.3) 2.0 (1.1)	ESS0230
2.0 (1.3)	
2.0 (1.3)	ESS0240

Level 0 Parent	ESS Child
2.0 (1.3) 2.0 (1.5)	ESS0250
2.0 (1.3)	
2.0 (1.3)	ESS0260
2.0 (1.5) 2.0 (1) 2.0 (1.3)	ESS0280
2.0 (1.1) 2.0 (1.2) 2.0 (1.3)	
2.0 (1)	
2.0 (1.5) 2.0 (1) 2.0 (1.3)	ESS0300
2.0 (1)	
2.0 (1.5) 2.0 (1) 2.0 (1.3)	
2.0 (1) 2.0 (1.2)	ESS0310
2.0 (1.4)	
2.0 (1.4)	ESS0320
3.0 (1) 2.0 (2) 2.0 (1.5) 2.0 (1.3) 2.0 (1)	ESS0340
2.0 (1.4) 2.0 (1.2) 2.0 (1.5) 2.0 (1.3) 2.0 (1)	
2.0 (1.5) 2.0 (1.3) 2.0 (1)	
2.0 (1.5) 2.0 (1.3) 2.0 (1)	
2.0 (1)	
2.0 (1)	ESS0370
2.0 (2) 2.0 (1.5) 2.0 (1.2) 2.0 (1) 2.0 (1.3) 2.0 (1.4)	ESS0380
2.0 (1.4)	
2.0 (1.4)	ESS0390

Level 0 Parent	ESS Child
2.0 (1.2) 2.0 (1.3) 2.0 (1.4) 2.0 (1.5)	ESS0570
2.0 (2) 2.0 (1)	
2.0 (1.2) 2.0 (1.4) 2.0 (1.5) 2.0 (1.3) 2.0 (1)	
2.0 (1.1)	
2.0 (1)	ESS0640
2.0 (1.2) 2.0 (1.4) 2.0 (1.5) 2.0 (1.3) 2.0 (1)	ESS0650
2.0 (1.1)	
2.0 (1)	
2.0 (1) 2.0 (1.5) 2.0 (1.3)	ESS0700
2.0 (1.1)	
2.0 (1)	